EXHIBIT C

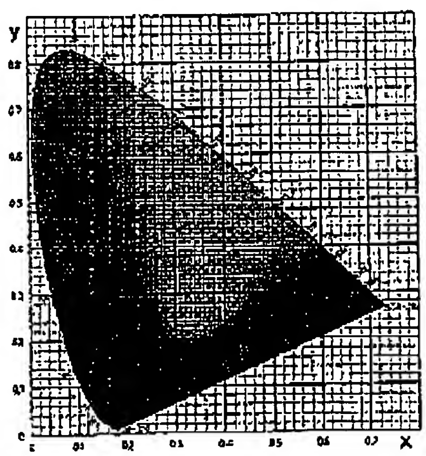
SUPPLEMENTAL READINGS
useful information about related subjects

COLOR GAMUTS

Starting With XYZ

The creation of a global color standard embracing the most important color gamuts and enabling consistant color communications is vital for the growth of color reproduction. The CIE, the Commission Internationale de l'Eclairage, plays a leading role in the definition of color systems.

In 1931 the CIE developed the XYZ color system, also called the "norm color system." This system is often represented as a two-dimensional graphic which more or less corresponds to the shape of a sail.



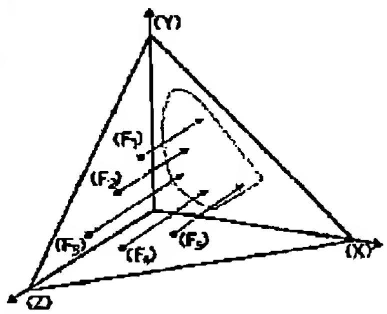
The red components of a color are tallied along the x (horizontal) axis of the coordinate plane and the green components along the y (vertical) axis. In this way every color can be assigned a particular point on the coordinate plane. As you can see, colors on the left tend toward gray, which means that their spectral purity is decreased.

What is not taken into consideration in the above model is the variant of brightness. If it were, the sail-like figure would look like a flat sack. More on that later.

This Isn't Rocket Science...Really!

The CIE color standard is based on imaginary primary colors XYZ -- which don't exist physically. They are purely theoretical and independent of device-dependent color gamuts such as RGB or CMYK. These virtual primary colors have, however, been selected so that all colors which can be perceived by the human eye lie within their color space.

The XYZ system is based on the response curves of the eye's three color receptors. Since these differ slightly from person to person, CIE has defined a "standard observer" whose spectral response corresponds more or less to the average response of the population. This objectifies the colorimetric determination of colors.



The three primary colors of the CIE XYZ reference system call for a spatial model with coordinates (X), (Y) and (Z), which is drawn as a chromaticity triangle. To arrive at a two-dimensional diagram (the sail shape), this chromaticity triangle is projected into the red-green plane.

This is only meaningful, however, if appropriate standardization is performed at the same time which allows the lost value (Z) to be read from the new two-dimensional model. This is achieved by introducing the chromaticity coordinates x, y and z. They are defined as follows:

- $x = X / (X + Y + Z)$
- $y = Y / (X + Y + Z)$
- $z = Z / (X + Y + Z)$

where $x + y + z = 1$

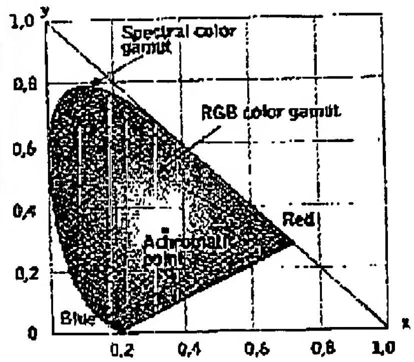
The value z of any desired color can be obtained by subtracting the chromaticity coordinates x and y from 1:

$1 - x - y = z$

However, the CIE chromaticity diagram does have a few drawbacks:

- Brightness is difficult to include
- There is a discrepancy between perceived color differences and the actual spacing of color in the system.

Adding Brightness to Color



A color is not defined fully by its chromaticity (x and y). A brightness coefficient also needs to be specified. The eye response curve for green is standardized in the XYZ system so that it simultaneously reflects the sensation of brightness. That makes it identical to the V (l) curve. A color is only described in full if it contains the values x and y plus the brightness coefficient Y.

In the standard color triangle, the right-angled chromaticity triangle drawn between zero, x = 1 and y =1 represents the boundaries of this reference system. Chromaticities cannot lie outside the triangle. The closed curve section represents the position of the spectral colors.

While it is possible to define colors between the triangle and spectral color gamut, they are only realized on virtual basis, i.e. not physically. The primary colors RGB of a reproduction device -- such as a color monitor -- form a triangle within the spectral color gamut. That triangle represents a smaller color gamut with the achromatic point more or less in the center.

Exactly!

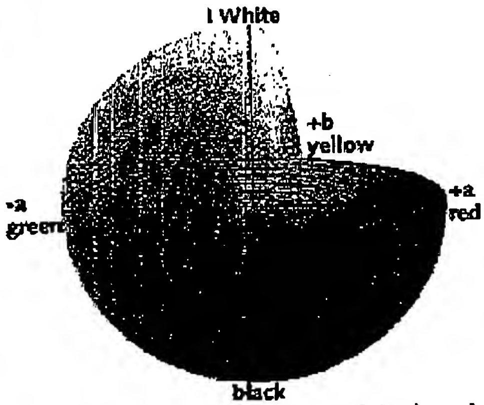
The introduction of the CIE color system made it possible to transform color determination from a quality-describing process -- "I want a bright red -- into a process which can be expressed in exact quantitative and numerical terms.

In addition to the quantitative judgement it allows, the CIE color space permits the results of additive color mixing to be presented in simple form. The results always lie on straight lines between the colors being mixed. The CIE standard also allows any desired color transformations from one color gamut to another. For example, the transformation of a given color from the RGB color gamut of a monitor to the CMYK gamut of a printing process is facilitated by this standard.

Perceived Color Differences

As mentioned, one problem with the XYZ color system is that colorimetric distances between the individual colors don't correspond to perceived color differences.

For exampl , in the figure above, a difference between green and greenish-yellow is relatively large, whereas the distance distinguishing blue and red is quite small.

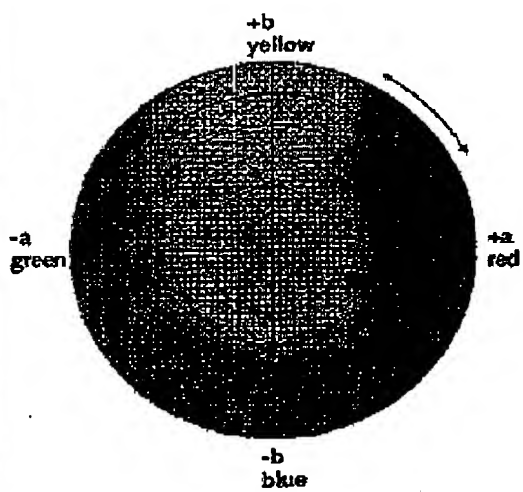


CIELAB: CIE solved this problem in 1976 with the development of the Lab color space. A three-dimensional color space was the result.

In this model, perceived color differences correspond to measured linear colormetric distances. The "a" axis extends from green (-a) to red (+a) and the "b" axis from blue (-b) to yellow (+b). The brightness (L) increases from the bottom to the top of the 3-dimensional model.

With CIELAB what you see is what you get -- and that's exactly what you want in color management.

CIELAB and Brightness



A horizontal cross-section of the CIELAB model reveals a plane which depicts all values of the same brightness. That means every color can be named exactly using its specific a, b values together with its brightness, L.

The important aspect of this color space is that it is device independent -- completely independent of weather, mood or scanner or color copier -- and is therefore objective.

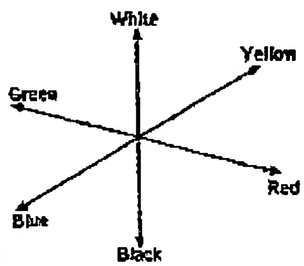
Thus, the same combination of a, b, and L values always refers to the same color...no matter what.

CIELAB Color Space

Color vision is complex. While the retina at first registers three color stimuli -- relating to red, green and blue light rays -- it is not until a further processing stage that three sensations are generated:

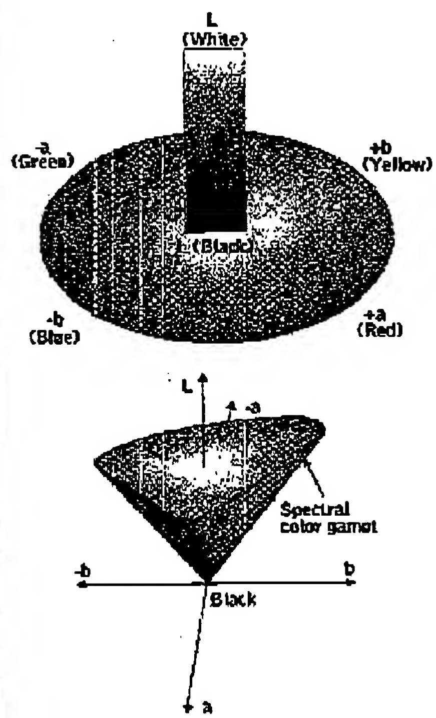
- a red-green sensation
- a yellow-blue sensation
- a brightness sensation

These sensations are used to develop a system known as the complementary color system. It is based on the differences of three elementary color pairs: red-green, yellow-blue and black-white.



You know from experience that red can never contain green components, blue cannot contain yellow components and white never contains black. It follows that in a reference system which has been designed correctly -- in visual sensation terms -- the achromatic brightness information and the color information should be separated not only quantitatively but qualitatively.

Hue and chroma are defined by the coordinates a and b which can have both positive and negative values. As with the standard color triangle, this color system represents all conceivable colors.

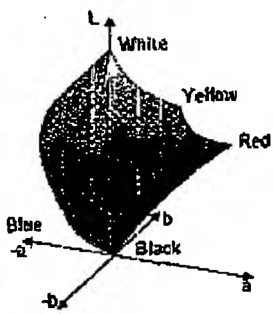


Thus, numerical values for chroma and hue are derived from a and b:

- **Hue:** h = arctan (b/a) (This corresponds to the angle between the color vector and the +a axis)
- **Chroma:** c = (a2 + b2)1/2 (This corresponds to the distance between the color locus and the mid-point)
- **Brightness:** L (The third characteristic is represented vertically by means of a brightness scale, designated L, with scale values ranging from 0 for black to 100 for white)

A color gamut in CIELAB appears to the right (in idealized form, of course)

For the sake of clarity, the different brightnesses of the spectral color curve are not shown in their entirety. The model is delimited at the top by a horizontal section. On the outer surface lie all colors of maximum chroma. As colors become darker they lose chroma. This is logical considering that, when the minimum brightness value is reached, every color becomes black and the chroma value is zero.



Thus, a color gamut based on real colors would actually look like as you see to the immediate right. And, as we understand the way color exists in the real world, two things are clear:

- As the brightness increases or decreases, the chroma reduces to zero when white or black is reached.
- In contrast to the CIE color triangle, the connecting lines between the primary colors are not straight.

The reason for this lies in the visual equispacing of colors in CIELAB. This has been achieved through a non-linear transformation of the XYZ values into CIELAB values.

The formulas for the transformation of XYZ to CIELAB are based on:

- L = 116 Y1/3 - 16
- a = 500 (X1/3 - Y1/3)
- b = 200 (Y1/3 - Z1/3),

with X, Y and Z standardized to 1.

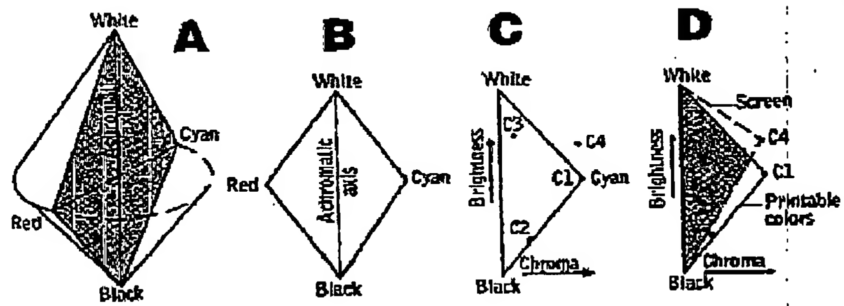
Advantages of CIELAB in Color Reproduction

The CIELAB color space has many advantages. Above all, it is not dependent on any particular device independent so you can set colors as you perceive them when operating a reproduction system.

CIELAB color space -- like the XYZ color space -- is able to represent all real color gamuts as subsets.

Assume a reproduction system which is based on the RGB color space. The RGB color values need to be converted to CMYK color values for the printing process. The two color spaces coincide in

neither size nor location. Due to the fact that the system has RGB as its reference system, it follows that colors of the CMYK color space which cannot be represented in RGB cannot be printed in CMYK. RGB acts as a restriction to CMYK. For example, chromatic cyan cannot be represented on the RGB monitor and, under such circumstances, becomes a non-reproducible color.



To illustrate, look at the cross-section of a stylized color gamut (figure A). In the next illustration (figure B), you now see the cyan-red plane. The problem can be shown in simpler form if only one of the two planes is observed -- in this case the cyan plane (figure C).

The colors depicted show:

- C1 -- cyan with maximum chroma
- C2 -- cyan with the highest possible chroma for this brightness value
- C3 -- a pale near-achromatic cyan
- C4 -- a cyan which lies outside the color space

In the diagram, all the colors have the same hue: cyan. It is possible to reproduce them all -- except C4 which lies outside the color space. If the printable colors are included, the two color spaces are not identical (figure D).

The fact that the two color gamuts overlap means that only the colors in a common subset (shaded area) can be reproduced both on the monitor and in print.

In a device-dependent reference system like RGB or CMYK, colors lying outside their reference system cannot be reproduced even if they are present in the target color gamut. The advantage of global reference systems such as the XYZ or CIELAB, which are unrestricted, become obvious through this example.

More Reading